# Chapter 2
# General Design Considerations

## 2-1. Types of Concrete Gravity Dams

Basically, gravity dams are solid concrete structures that maintain their stability against design loads from the geometric shape and the mass and strength of the concrete. Generally, they are constructed on a straight axis, but may be slightly curved or angled to accommodate the specific site conditions. Gravity dams typically consist of a nonoverflow section(s) and an overflow section or spillway. The two general concrete construction methods for concrete gravity dams are conventional placed mass concrete and RCC.

*a. Conventional concrete dams.*

(1) Conventionally placed mass concrete dams are characterized by construction using materials and techniques employed in the proportioning, mixing, placing, curing, and temperature control of mass concrete (American Concrete Institute (ACI) 207.1 R-87). Typical overflow and nonoverflow sections are shown on Figures 2-1 and 2-2. Construction incorporates methods that have been developed and perfected over many years of designing and building mass concrete dams. The cement hydration process of conventional concrete limits the size and rate of concrete placement and necessitates building in monoliths to meet crack control requirements. Generally using large-size coarse aggregates, mix proportions are selected to produce a low-slump concrete that gives economy, maintains good workability during placement, develops minimum temperature rise during hydration, and produces important properties such as strength, impermeability, and durability. Dam construction with conventional concrete readily facilitates installation of conduits, penstocks, galleries, etc., within the structure.

(2) Construction procedures include batching and mixing, and transportation, placement, vibration, cooling, curing, and preparation of horizontal construction joints between lifts. The large volume of concrete in a gravity dam normally justifies an onsite batch plant, and requires an aggregate source of adequate quality and quantity, located at or within an economical distance of the project. Transportation from the batch plant to the dam is generally performed in buckets ranging in size from 4 to 12 cubic yards carried by truck, rail, cranes, cableways, or a combination of these methods. The maximum bucket size is usually restricted by the capability of effectively spreading and vibrating the concrete pile after it is dumped from the bucket. The concrete is placed in lifts of 5- to 10-foot depths. Each lift consists of successive layers not exceeding 18 to 20 inches. Vibration is generally performed by large one-man, air-driven, spud-type vibrators. Methods of cleaning horizontal construction joints to remove the weak laitance film on the surface during curing include green cutting, wet sand-blasting, and high-pressure air-water jet. Additional details of conventional concrete placements are covered in EM 1110-2-2000.

(3) The heat generated as cement hydrates requires careful temperature control during placement of mass concrete and for several days after placement. Uncontrolled heat generation could result in excessive tensile stresses due to extreme gradients within the mass concrete or due to temperature reductions as the concrete approaches its annual temperature cycle. Control measures involve precooling and postcooling techniques to limit the peak temperatures and control the temperature drop. Reduction in the cement content and cement replacement with pozzolans have reduced the temperature-rise potential. Crack control is achieved by constructing the conventional concrete gravity dam in a series of individually stable monoliths separated by transverse contraction joints. Usually, monoliths are approximately 50 feet wide. Further details on temperature control methods are provided in Chapter 6.

*b. Roller-compacted concrete (RCC) gravity dams.* The design of RCC gravity dams is similar to conventional concrete structures. The differences lie in the construction methods, concrete mix design, and details of the appurtenant structures. Construction of an RCC dam is a relatively new and economical concept. Economic advantages are achieved with rapid placement using construction techniques that are similar to those employed for embankment dams. RCC is a relatively dry, lean, zero slump concrete material containing coarse and fine aggregate that is consolidated by external vibration using vibratory rollers, dozer, and other heavy equipment. In the hardened condition, RCC has similar properties to conventional concrete. For effective consolidation, RCC must be dry enough to support the weight of the construction equipment, but have a consistency wet enough to permit adequate distribution of the past binder throughout the mass during the mixing and vibration process and, thus, achieve the necessary compaction of the RCC and prevention of undesirable segregation and voids. The consistency requirements have a direct effect on the mixture proportioning requirements (ACI 207.1 R-87). EM 1110-2-2006, Roller Compacted Concrete, provides detailed

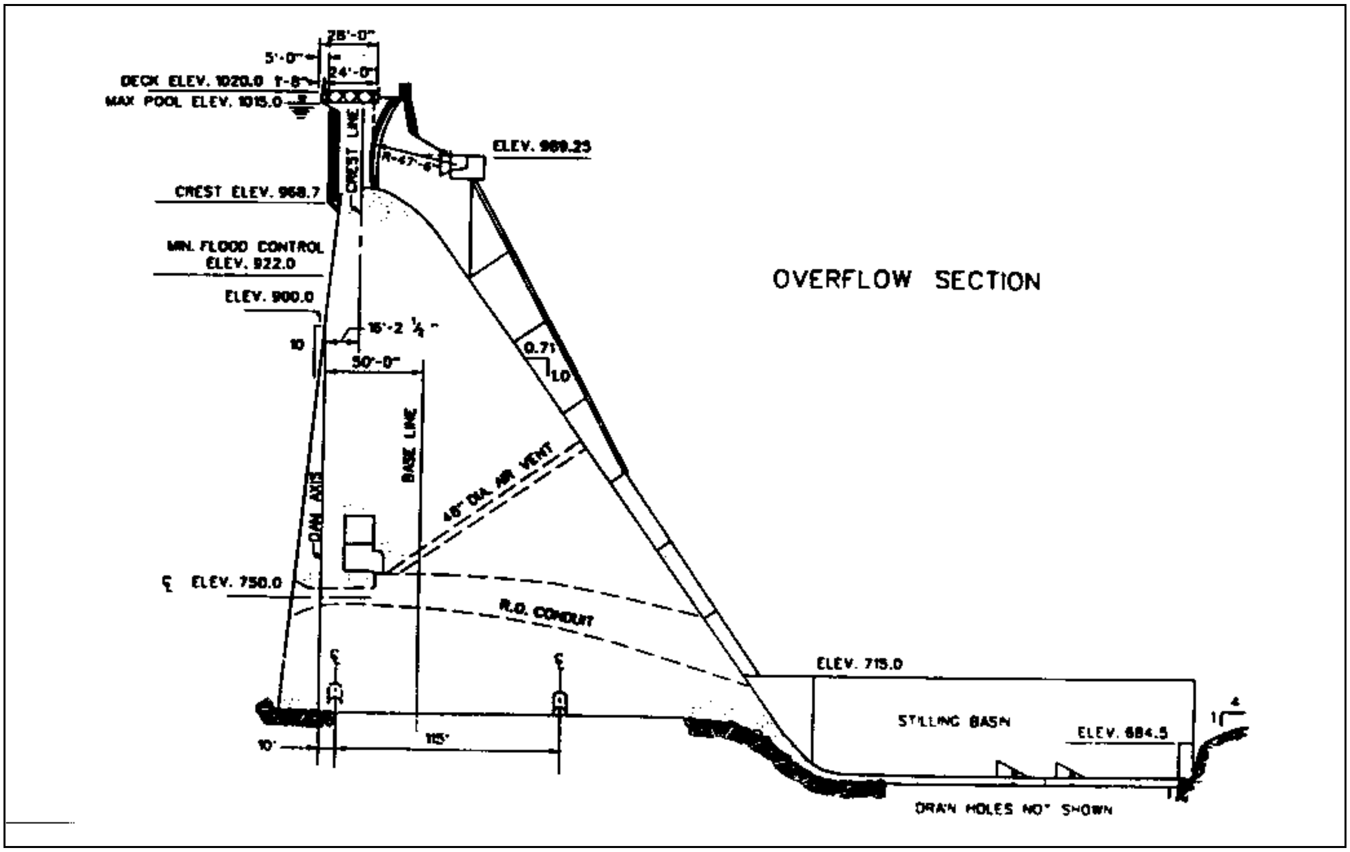


**Figure 2-1. Typical dam overflow section**

guidance on the use, design, and construction of RCC. Further discussion on the economic benefits and the design and construction considerations is provided in Chapter 9.

## 2-2. Coordination Between Disciplines

A fully coordinated team of structural, material, and geotechnical engineers, geologists, and hydrological and hydraulic engineers should ensure that all engineering and geological considerations are properly integrated into the overall design. Some of the critical aspects of the analysis and design process that require coordination are:

*a. Preliminary assessments of geological data, subsurface conditions, and rock structure.* Preliminary designs are based on limited site data. Planning and evaluating field explorations to make refinements in design based on site conditions should be a joint effort of structural and geotechnical engineers.

*b. Selection of material properties, design parameters, loading conditions, loading effects, potential failure mechanisms, and other related features of the analytical models.* The structural engineer should be involved in these activities to obtain a full understanding of the limits of uncertainty in the selection of loads, strength parameters, and potential planes of failure within the foundation.

*c. Evaluation of the technical and economic feasibility of alternative type structures.* Optimum structure type and foundation conditions are interrelated. Decisions on alternative structure types to be used for comparative studies need to be made jointly with geotechnical engineers to ensure the technical and economic feasibility of the alternatives.

*d. Constructibility reviews in accordance with ER 415-1-11.* Participation in constructibility reviews is necessary to ensure that design assumptions and methods of construction are compatible. Constructibility reviews should be followed by a memorandum from the Directorate of Engineering to the Resident Engineer concerning special design considerations and scheduling of construction visits by design engineers during crucial stages of construction.

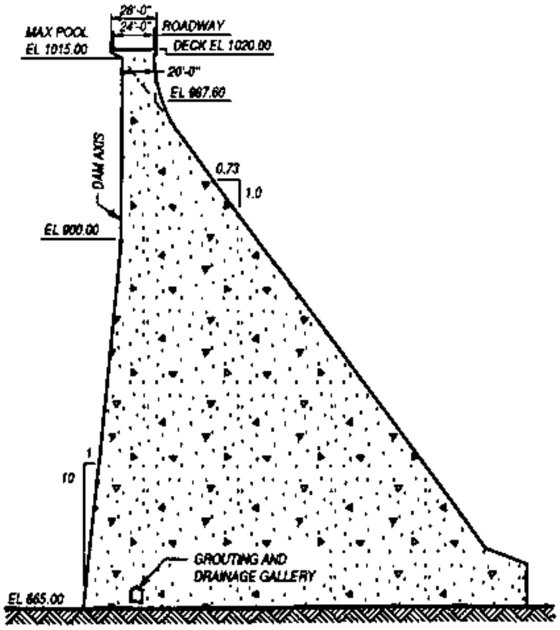


**Figure 2-2. Nonoverflow section**

*e. Refinement of the preliminary structure configuration to reflect the results of detailed site explorations, materials availability studies, laboratory testing, and numerical analysis.* Once the characteristics of the foundation and concrete materials are defined, the founding levels of the dam should be set jointly by geotechnical and structural engineers, and concrete studies should be made to arrive at suitable mixes, lift thicknesses, and required crack control measures.

*f. Cofferdam and diversion layout, design, and sequencing requirements.* Planning and design of these features will be based on economic risk and require the joint effort of hydrologists and geotechnical, construction, hydraulics, and structural engineers. Cofferdams must be set at elevations which will allow construction to proceed with a minimum of interruptions, yet be designed to allow controlled flooding during unusual events.

*g. Size and type of outlet works and spillway*. The size and type of outlet works and spillway should be set jointly with all disciplines involved during the early stages of design. These features will significantly impact on the configuration of the dam and the sequencing of construction operations. Special hydraulic features such as water quality control structures need to be developed jointly with hydrologists and mechanical and hydraulics engineers.

*h. Modification to the structure configuration during construction due to unexpected variations in the foundation conditions.* Modifications during construction are costly and should be avoided if possible by a comprehensive exploration program during the design phase. However, any changes in foundation strength or rock structure from those upon which the design is based must be fully evaluated by the structural engineer.

## 2-3. Construction Materials

The design of concrete dams involves consideration of various construction materials during the investigations phase. An assessment is required on the availability and suitability of the materials needed to manufacture concrete qualities meeting the structural and durability requirements, and of adequate quantities for the volume of concrete in the dam and appurtenant structures. Construction materials include fine and coarse aggregates, cementitious materials, water for washing aggregates, mixing, curing of concrete, and chemical admixtures. One of the most important factors in determining the quality and economy of the concrete is the selection of suitable sources of aggregate. In the construction of concrete dams, it is important that the source have the capability of producing adequate quantitives for the economical production of mass concrete. The use of large aggregates in concrete reduces the cement content. The procedures for the investigation of aggregates shall follow the requirements in EM 1110-2-2000 for mass concrete and EM 1110-2-2006 for RCC.

## 2-4. Site Selection

*a. General.* During the feasibility studies, the preliminary site selection will be dependent on the project purposes within the Corps' jurisdiction. Purposes applicable to dam construction include navigation, flood damage reduction, hydroelectric power generation, fish and wildlife enhancement, water quality, water supply, and recreation. The feasibility study will establish the most suitable and economical location and type of structure. Investigations will be performed on hydrology and meteorology, relocations, foundation and site geology, construction materials, appurtenant features, environmental considerations, and diversion methods.

*b. Selection factors.*

(1) A concrete dam requires a sound bedrock foundation. It is important that the bedrock have adequate shear strength and bearing capacity to meet the necessary stability requirements. When the dam crosses a major fault or shear zone, special design features (joints, monolith lengths, concrete zones, etc.) should be incorporated in the design to accommodate the anticipated movement. All special features should be designed based on analytical techniques and testing simulating the fault movement. The foundation permeability and the extent and cost of foundation grouting, drainage, or other seepage and uplift control measures should be investigated. The reservoir's suitability from the aspect of possible landslides needs to be thoroughly evaluated to assure that pool fluctuations and earthquakes would not result in any mass sliding into the pool after the project is constructed.

(2) The topography is an important factor in the selection and location of a concrete dam and its appurtenant structures. Construction as a site with a narrow canyon profile on sound bedrock close to the surface is preferable, as this location would minimize the concrete material requirements and the associated costs.

(3) The criteria set forth for the spillway, powerhouse, and the other project appurtenances will play an important role in site selection. The relationship and adaptability of these features to the project alignment will need evaluation along with associated costs.

(4) Additional factors of lesser importance that need to be included for consideration are the relocation of existing facilities and utilities that lie within the reservoir and in the path of the dam. Included in these are railroads, powerlines, highways, towns, etc. Extensive and costly relocations should be avoided.

(6) The method or scheme of diverting flows around or through the damsite during construction is an important consideration to the economy of the dam. A concrete gravity dam offers major advantages and potential cost savings by providing the option of diversion through alternate construction blocks, and lowers risk and delay if overtopping should occur.

## 2-5. Determining Foundation Strength Parameters

*a. General.* Foundation strength parameters are required for stability analysis of the gravity dam section. Determination of the required parameters is made by evaluation of the most appropriate laboratory and/or in situ strength tests on representative foundation samples coupled with extensive knowledge of the subsurface geologic characteristics of a rock foundation. In situ testing is expensive and usually justified only on very large projects or when foundation problems are know to exist. In situ testing would be appropriate where more precise foundation parameters are required because rock strength is marginal or where weak layers exist and in situ properties cannot be adequately determined from laboratory testing of rock samples.

*b. Field investigation.* The field investigation must be a continual process starting with the preliminary geologic review of known conditions, progressing to a detailed drilling program and sample testing program, and concluding at the end of construction with a safe and operational structure. The scope of investigation and sampling should be based on an assessment of homogeneity or complexity of geological structure. For example, the extent of the investigation could vary from quite limited (where the foundation material is strong even along the weakest potential failure planes) to quite extensive and detailed (where weak zones or seams exist). There is a certain minimum level of investigation necessary to determine that weak zones are not present in the foundation. Field investigations must also evaluate depth and severity of weathering, ground-water conditions (hydrogeology), permeability, strength, deformation characteristics, and excavatibility. Undisturbed samples are required to determine the engineering properties of the foundation materials, demanding extreme care in application and sampling methods. Proper sampling is a combination of science and art; many procedures have been standardized, but alteration and adaptation of techniques are often dictated by specific field procedures as discussed in EM 1110-2-1804.

*c. Strength testing.* The wide variety of foundation rock properties and rock structural conditions preclude a standardized universal approach to strength testing. Decisions must be made concerning the need for in situ testing. Before any rock testing is initiated, the geotechnical engineer, geologist, and designer responsible for formulating the testing program must clearly define what the purpose of each test is and who will supervise the testing. It is imperative to use all available data, such as results from geological and geophysical studies, when selecting representative samples for testing. Laboratory testing must attempt to duplicate the actual anticipated loading situations as closely as possible. Compressive strength testing and direct shear testing are normally required to determine design values for shear strength and bearing capacity. Tensile strength testing in some cases as well as consolidation and slakeability testing may also be necessary for soft rock foundations. Rock testing procedures are discussed in the *Rock Testing Handbook* (US Army Engineer Waterways Experiment Station (WES) 1980) and in the International Society of Rock Mechanics, "Suggested Methods for Determining Shear Strength," (International Society of Rock Mechanics 1974). These testing methods may be modified as appropriate to fit the circumstances of the project.

*d. Design shear strengths.* Shear strength values used in sliding analyses are determined from available laboratory and field tests and judgment. For preliminary designs, appropriate shear strengths for various types of rock may be obtained from numerous available references including the US Bureau of Reclamation Reports SP-39 and REC-ERC-74-10, and many reference texts (see bibliography). It is important to select the types of strengthtests to be performed based upon the probable mode of failure. Generally, strengths on rock discontinuities would be used for the active wedge and beneath the structure. A combination of strengths on discontinuities and/or intact rock strengths would be used for the passive wedge when included in the analysis. Strengths along preexisting shear planes (or faults) should be determined from residual shear tests, whereas the strength along other types of discontinuities must consider the strain characteristics of the various materials along the failure plane as well as the effect of asperities.